FACILITY FOR INTENSE DIAGNOSTIC NEUTRAL BEAM (IDNB) DEVELOPMENT

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An intense, pulsed neutral beam source is under development for use as a probe beam on hot, burning plasmas such as in the international thermonuclear experimental reactor (ITER) which is presently in the planning stage.[1] A pulsed, neutral hydrogen beam of 10s of kilo amperes of current can have an alpha particle, charge-exchange-recombination-spectroscopy (alpha-CHERS) signal-to-noise ratio of ~10.[2] This beam would allow the measurement, on a single pulse of a few hundred nanoseconds duration, of the local alpha particle distribution function as well as other features of the tokamak plasma such as current density profile, impurity density, and micro-turbulence spectrum. The cross-sections for the CHERS diagnostic dictate operation with proton energies greater than ~$50keV$. A pulsed neutral hydrogen source of this voltage and intensity can be achieved by neutralizing the ion flux from a magnetized ion-diode. The cross-sections for attachment and stripping, when coupled with scaling from Child-Langmiur, space-charge-limited, ion-current flow imply operation below ~$100keV$ for maximum neutral fluence. The development of a flashover-anode, ion source for forthcoming evaluation of a neutralizing section is described below. This source operates in the accelerator voltage range 70 to $100keV$. Eventually, the flashover-anode, magnetized ion-diode will be replaced with a plasma-anode, magnetized ion-diode.

I. Experimental Configuration

The high voltage driver for the ion diode is a +/- $60kV$ array of Scyllac capacitors with a Maxwell 4-section rail gap array similar to Shiva-Star at Phillips Laboratory. The driver unit can accommodate up to 12 capacitors in a configuration with 6 positively charged and 6 negatively charged, although presently there are 4 each $1.8\,\mu F$ capacitors in each of the arrays for a net system capacitance of $3.6\,\mu F$. A series resistance of .45 *ohms* is used to limit the current and dissipate most of the energy after gap closure in the ion diode. The high-voltage-system inductance is ~$200nH$. Ignitron switched, low-voltage slow banks are used to energize the diode magnets.[3] Under typical operating conditions, full current operation (~$20kA$) would result in ~5% voltage drop with a current pulse width of 0.9μsec.

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The flashover-anode, magnetized ion-diode is similar to previous designs, except that this work is at the low end of previous high-voltage operation. The layout of the diode is shown in Figure 1.

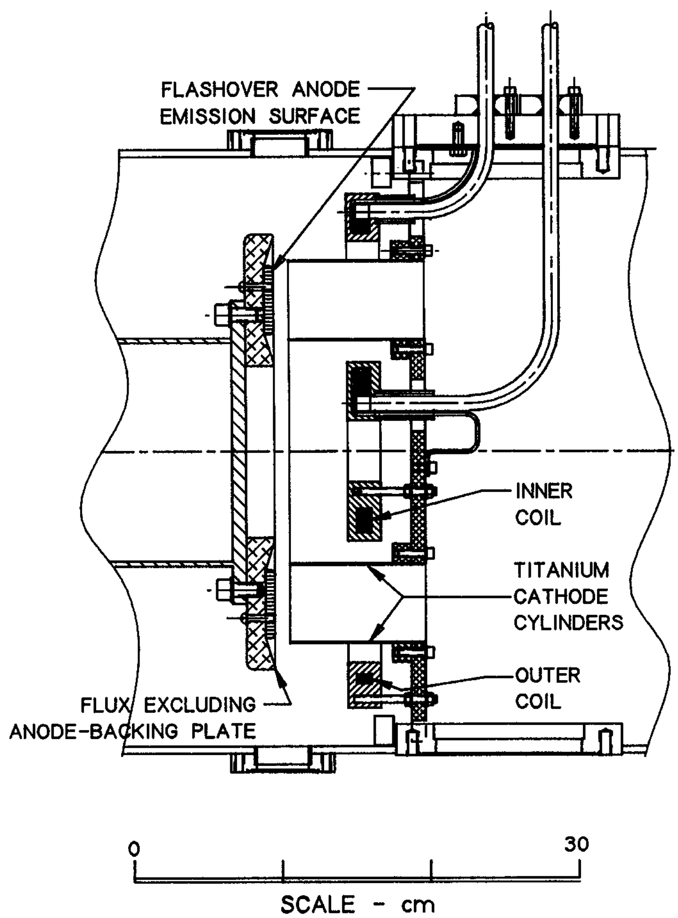

Figure 1: Flashover-anode, magnetized, ion-diode

Typical insulating fields are 1.5 kilogauss, the typical anode-cathode gap setting is $1.0cm$, and the active emission area of the anode is $250cm^2$. A number of techniques have been used to light-up the flashover anode. An array of .030" diameter pins has been installed through the 0.250" thick acrylic anode material in an approximately square pattern 0.20" on centers.[4] Performance of the diode is optimum after a number of conditioning shots have eroded the plastic so that the ends of the pins are exposed by ~.02". Combs of electron emission points made from window screen have been installed on the cathode cylinders at the anode-cathode gap with the .150" fingers aimed radially toward the flow region. Since the flashover anode requires a period of time to turn-on, the anode edges have been cut away to

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1993**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Facility For Intense Diagnostic Neutral Beam (Idnb) Development**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Los Alamos National Laboratory Los Alamos, NM 87545**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

lengthen the distance from cathode to anode, without increasing the anode-cathode gap. This has increased the insulation period, before gap closure to allow time for the anode to turn-on.

Polyethylene has also been evaluated as an anode material, but does not appear to turn on as readily as acrylic at the IDNB operating voltage. For some of the initial shots, at 70kV, a low-inductance array of ceramic high voltage capacitors was installed behind the anode plate between the anode plate and ground. The system inductance and the $.002\mu F$ capacitance provided a ringing over-voltage when the capacitor bank rail gaps were fired. Recent shots at 100kV do not require this to turn-on the flashover anode.

II. Experimental Results

The current in the annular ion flow is measured with balanced, shielded, Rogowski probes located inside the outer cathode and outside the inner cathode. The balanced Rogowski probes are located ~10cm downstream of the anode-cathode gap, near the beam stop. This system clearly distinguishes between beam current and the anode-cathode breakdown that follows the gap closure after the beam pulse. The observed currents are consistent with electrons pulled into the flow from the cathode cylinders, along the primarily radial magnetic field, to neutralize the space charge of the ion flow. In the anode-cathode breakdown the total current to the cathode structure is as high as 140kA (limited by the 0.45Ω series resistor), which is ~10x the net ion current. The ion current is also observed as a "feature" on the leading edge of the total current measured with the system Rogowski probe.

Voltage on the anode structure is measured by a resistive voltage divider and a capacitive probe located near the vacuum interface. The collapse of the impedance at gap closure is clearly observable on the voltage waveform. Current and voltage at the transmission line for the ion flow are shown for a typical shot at $88kV$ source voltage in Figure 2. The flashover-anode, ion source turns on after ~600ns, the beam is extracted for 200 to 300ns at the driver voltage minus the drop in the series resistor ($\leq 7.5kV$). The subsequent impedance collapse results in a fall of the voltage across the gap and substantial current to the cathode structure. The R-C decay of the capacitor-bank, series-resistor system is observed on the tail of the total current.

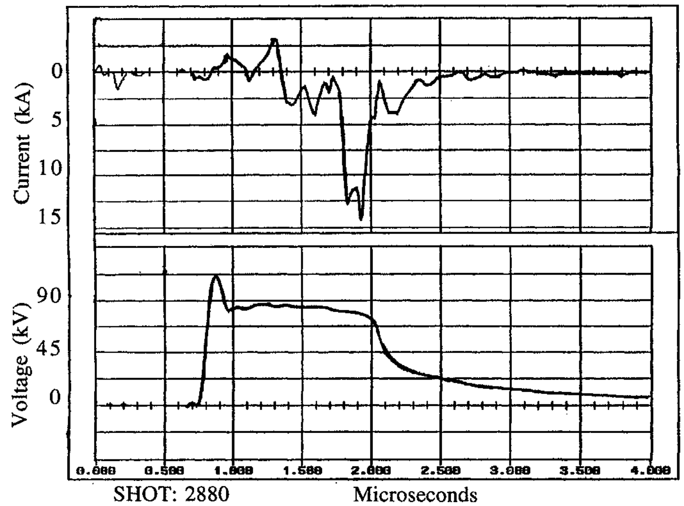

Figure 2: Ion-flow current and transmission-line voltage of the IDNB at 88kV source voltage. The 0.45Ω current limiting resistor is between the capacitor bank and the voltage probe.

The energy in the ion flow is measured with an infrared imaging calorimeter.[5] A 3 mil thick stainless-steel beam stop is viewed from the back side (coated for emmissivity) to observe the deposition pattern. A false-color-contour picture of the intensity gives the pattern with $0.67 J/cm^2$ resulting in a $20° C$ temperature rise. The calorimeter system is shown in Figure 3. The beam energy, from the measured current and voltage agrees to better than a factor of 2 with the calorimeter data summed over the entire area. The peak energy density is a factor of two below the blow-off limit for the beam stop material and the ion energies of the IDNB. Peak currents as high as $20kA$ have been observed at $100 kV$ source voltage. On some shots the diode impedance collapses as the current is rising.

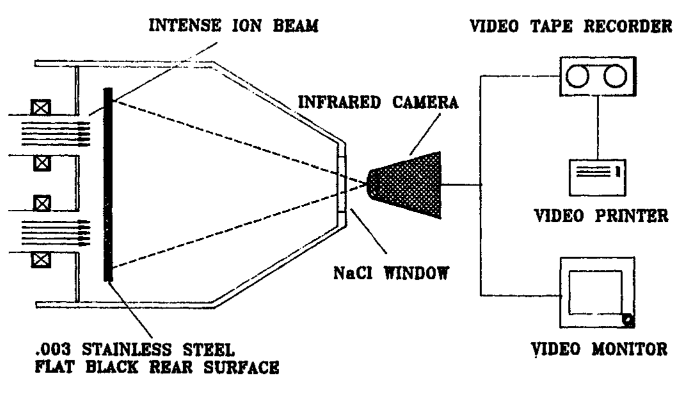

Figure 3: Infrared-imaging calorimeter system

The magnetic field structure has been calculated for the IDNB diode configuration using the independently-adjustable coil currents which were experimentally determined to optimize the balance between delaying the gap closure as long as possible and turning-on the anode. Simulations with the code Flux-2D indicate that this field shape has equi-flux contours parallel to the emitting surface of the plastic anode— a distance of .250 inches in front of the flux-excluding, anode-backing plate.[6]

III. Summary

Ion flows have been generated with a flashover-anode, magnetized, ion-diode operating 70 to 100kV with maximum currents up to 10 to 20kA. At these currents the emission level is 40 to 80 A/cm^2 which is as much as 30 times the Child-Langmiur current density for the standard gap and operating voltage. This initial, flash-over-anode beam source has been developed to evaluate a hydrogen-puff-valve neutralizer section shown in Figure 4. The annular region which is aligned with the cathode cylinders will be puff-filled to a pressure of $\sim 10^{-2}$ *Torr* prior to generating the ion beam. Input and output properties of the ion-neutral flow will be measured with a Thomson Parabola (ion species and energy) and the infrared calorimeter (energy of the total flow). Balanced Rogowski current probes will be located at four positions along the neutralizer section.

The ultimate ion source for the diagnostic beam will be a plasma-anode, magnetized, ion-diode.[7] Design of this source is presently underway.

This work supported by U. S. Department of Energy Contract #W-7405-ENG-36.

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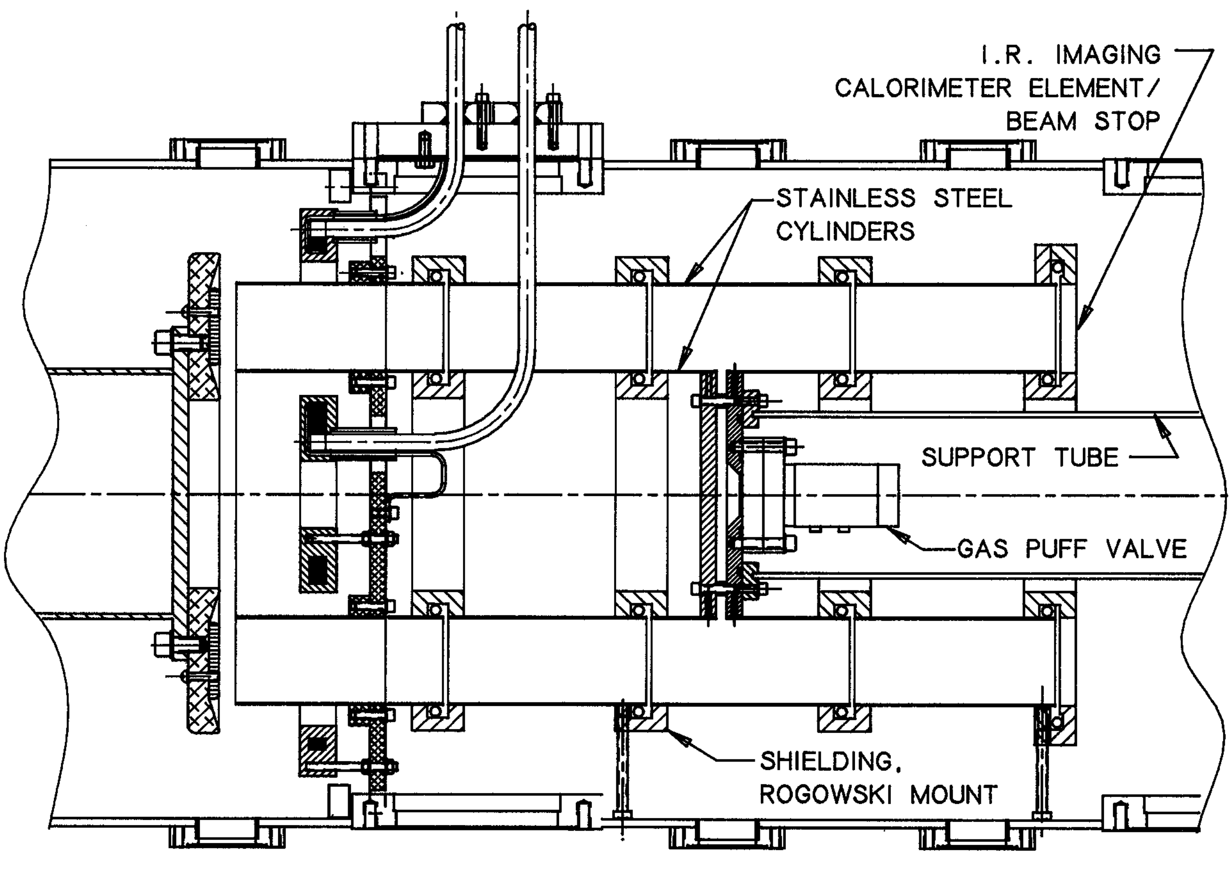

Figure 4: Neutralizer section for the IDNB. Balanced Rogowski current probes at four locations inside and outside the flow region. Magnet system for electron flow suppression not shown.